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NANTEN Observations of the LMC: Giant Molecular Clouds as Formation Sites of Stellar Clusters

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Abstract. A CO survey of the LMC has been completed in the J = 1–0 carbon monoxide emission at 2.6 mm wavelength with NANTEN. This survey has revealed the first complete sample of giant molecular clouds (GMCs) in the LMC at a linear resolution of $\sim$ 40 pc. The GMCs exhibit a good spatial correlation with youngest stellar clusters often associated with the giant H II regions. The ages of clusters associated with GMCs are fairly young, $\lesssim$ 10 Myr, demonstrating that cluster formation is on-going in these GMCs. In addition, compact groups of the young clusters are often found at the peak position of the GMCs, e.g., N159 and N44, while much looser groups are away from the GMCs. This suggests that the clusters are formed in groups and are dispersed as they become old.

1. Introduction

The Large Magellanic Cloud (LMC) contains numerous gravitationally bound young rich clusters of $\sim 10^4$ stars. These clusters called "populous clusters" apparently resemble globular clusters in the Galactic halo, although they contain $\sim$ 10 times less stars than a globular cluster. These bound clusters, showing marked contrast with unbound open clusters in the Galactic disk, may provide a unique clue to understand formation of globular clusters that happened in the early age of the Galaxy.

We have performed a new high resolution survey of molecular clouds toward the whole LMC in the 2.6 mm CO emission with NANTEN, a 4-m radio telescope installed at Las Campanas Observatory, Chile (Fukui et al. 1999; Mizuno et al. 2000; Yamaguchi et al. 2001). This survey has covered fully 6° × 6° area at $\sim$ 40 pc resolution, and has allowed us to have complete view of the GMCs for the first time in a single galaxy. We have thereby successfully identified the molecular clouds where young stellar clusters are being formed.

2. Formation Sites of Populous Clusters

A comparison with young stellar clusters has demonstrated that at least 1/3 of the CO clouds are the on-going sites of cluster formation (Fukui et al. 1999). The rest of the CO clouds, particularly massive ones with little sign of star formation, should be the future sites of cluster formation, since they exhibit

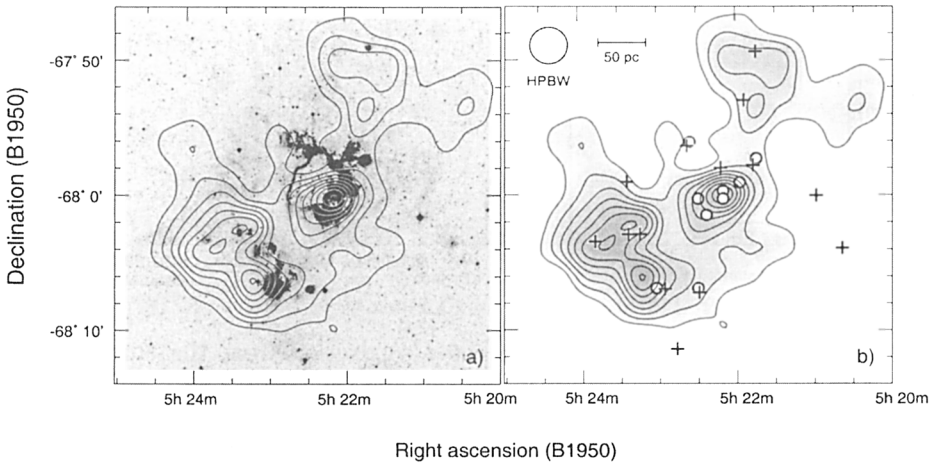

Figure 1. (a) Velocity-integrated intensity map of the CO emission superposed on the optical plates (ESO(R)) in N44 (DEM158, 160, 166, 167, 169) region. (b) Distribution of the GMCs and the young objects. The lowest contour and separation between contours are each 1.2 K km s^{-1}. The open circles are the clusters younger than 10 Myr (Bica et al. 1996). The crosses represent the positions of the H II regions (Davies et al. 1976).

physical properties common to cluster-forming CO clouds, in mass, velocity dispersion, and size. Nonetheless, according to the previous optical studies, these clouds are associated with only small H II regions or with no visible objects. It is highly probable that these clouds are the most recent sites of cluster formation.

The clusters associated with the GMCs are found to be significantly younger than those not associated with the GMCs. The relation between the cluster age and the GMCs are investigated in Fukui et al. 1999. We conclude that only the clusters with $\tau \lesssim 10$ Myr show significant correlation with the GMCs, and that the GMCs are probably dissipated within several Myr. This also suggests that the clusters associated with the GMCs have been just formed in the GMCs, and that those away from the GMCs are likely to be much older.

The clusters associated with the GMCs tend to be in a compact group of clusters. In the N44 region (Figure 1), compact groups of the young clusters are found near the peak of the massive GMCs. More quantitatively, $\sim 75\%$ of the clusters associated with the GMCs are found to be in pairs or in groups. In addition, the clusters appear to be spatially dispersed as they become old. In order to test these trends, apparent separations from a cluster to the nearest cluster are calculated for the clusters younger than 30 Myr. We classified the clusters into 3 groups according to their ages, i.e., the clusters with $\tau \lesssim 10$ Myr associated with the GMCs (a), those with $\tau \lesssim 10$ Myr not associated with the GMCs (b) and those with $10 \lesssim \tau \lesssim 30$ Myr (c). The clusters associated with the GMCs are likely to be younger than the rest, i.e., the clusters (a) are the youngest. The ages of the clusters (a) are probably a few Myr, and those of (b)

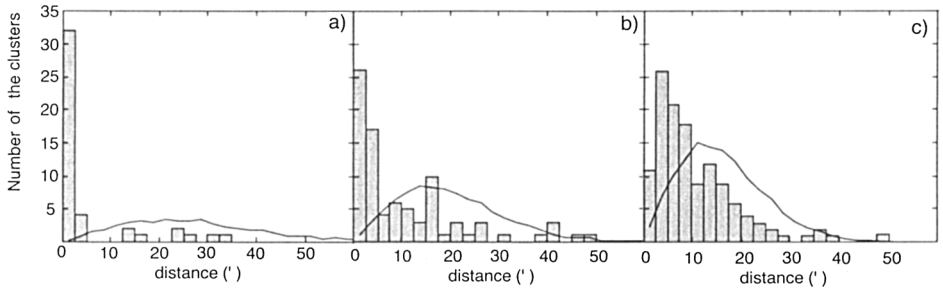

Figure 2. Histograms of projected separation from the clusters to the nearest cluster of comparable age; (a) the clusters of $\tau < 10$ Myr associated with the GMCs, (b) those of $\tau < 10$ Myr not associated with the GMCs, and (c) those with $10 < \tau < 30$ Myr. The lines represent the frequency distribution expected if the same number of clusters are distributed at random in the observed area.

are from a few to 10 Myr — since $\sim 35\%$ of the clusters younger than 10 Myr are associated with the GMCs, and thus, the lifetime of these clusters is estimated to be a few Myr by assuming steady cluster formation for ~ 10 Myr. The numbers of the classified clusters are (a) 47, (b) 88, and (c) 128, respectively. In Figure 2, we present histograms of the apparent separations of a cluster from the nearest cluster. The separations of the youngest clusters, (a), are significantly smaller than those expected from a purely random distribution (see Figure 2a). On the other hand, the older clusters show similar frequency distribution to those lying at random (see Figures 2b–c). Typical separations of the groups (a), (b) and (c) are $\sim$ 20–30 pc, $\sim$ 80 pc, and 120 pc, respectively, which also increase with their ages. From these results, we conclude that the clusters tend to be formed in groups in the massive GMCs of $\sim 10^6\ M_\odot$, and are scattered as they become old.

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